Assessment of Radionuclide Concentrations in Oil Producing Communities in Bayelsa West Senatorial District, Bayelsa State, Nigeria

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DOI: 10.56201/rjpst.v6.no2.2023.pg1.24

ABSTRACT
An assessment of radionuclide concentration in oil producing areas in Bayelsa West Senatorial District, Bayelsa State have been evaluated. In this study, a total of twenty five (25) soil, samples were collected for laboratory analysis. The survey was achieved using a factory calibrated Gamma Scout radiation meter and a Gamma Spectroscopy with Sodium Iodide (NA(TI) Detector used for counting and detection of radionuclide contentration of all samples. The results obtained in the study showed that the average concentrations for ^{40}K, ^{238}U and ^{232}Th in soil samples are valued at 520.888 ± 134.119 $Bqkg^{-1}$, 18.495 ± 4.983 $Bqkg^{-1}$ *and* 11.463 ± 2.472 $Bqkg^{-1}$ *respectively. The* Ra_{eq} *has an average value of* 74.675 ± 16.934 $Bqkg^{-1}$. *The* H_{ex} *has an average value of* 0.21 ± 0.049 *while the average value of* H_{in} *is* 0.26 ± 0.064 *which falls below the permissible level. The absorbed dose rate (D) due to ^{40}K, ^{238}U and ^{232}Th in soil samples has an average of* 37.23 ± 8.692 $nGyh^{-1}$. *This was also below the world average of* $60nGyh^{-1}$. *Annual effective dose equivalent (AEDE) has an average value of* 45.66 ± 10.654 μSvy^{-1}. *This was also below the world average value. Annual Gonadal Equivalent Dose (AGED) and Representative Gamma Index* (I_γ) *were valued at* 269.13 ± 63.095 $mSvy^{-1}$ *and* 0.59 ± 0.117 *respectively. Generally, the obtained value of ^{40}K was higher than the permissible level while ^{238}U and ^{232}Th where lower than the recommended standard value of* 400 $Bqkg^{-1}$, 33 $Bqkg^{-1}$ *and* 35 $Bqkg^{-1}$ *(UNSCEAR, 2000). Therefore, the use of the soil for industrial and domestic poses no radiological threat to human health.*

INTRODUCTION

Human environment is filled with both natural and man-made radionuclides that continuously disintegrate to release nuclear particles that can cause deleterious radiological health hazards. Naturally occurring radionuclides are the main sources of ionizing radiation in the environment. Human exposure to these ionizing radiations can cause adverse health effects when levels increase above background. Elevated radiation levels in the environment are typically due to human activities such as mining and milling of ores, nuclear power plants, handling of fuel cycle tail end products (Saleh, 2011). Oil and gas activities, such as exploitation, exploration, and drilling operations that release radionuclides into the surface environment, phosphate fertilizer processing, and fossil fuel combustion, have altered the natural ionizing radiation exposure to humans. This has increased natural radiation exposures to workers and members of the public. Onshore and offshore oil field workers in the Niger Delta region as well as other workers engaged in mineral

processing in underground mining sites are among the workers who are likely to be exposed (Agbalagba et al. 2010). When radiation dose or exposure rate are within tolerable bounds, the effects of radiation may be minimal. Nobody, however, has a perfect understanding of how low level radiation affects an environment (ICRP 1990). In order to prevent human overexposure to ionizing radiation beyond the established limit, radiation protection practices are guided by the ALARA (As Low as Reasonably Achievable) principle (Ramli et al., 2014).
Agricultural techniques, the atmosphere, different plant species, the properties of the soil, and environmental contamination all have an impact on the transport and uptake of natural radionuclides into edible plant portions. The main exposure route for people is through the transfer of radioactive materials from soil to food crops. Radium, thorium, potassium, and uranium radionuclides are among those emitted into the soil, water, and/or air, among other environmental matrices. According to several studies (Pandey et al. 2017, El-Taher et al. 2018), the concentrations of naturally occurring radium, thorium, and uranium are notably linked to the production of gamma rays.

Based on the dangers associated with ionizing radiation exposure, particularly from primordial or terrestrial sources, the background ionizing radiation levels in oil fields within the Bayelsa West senatorial district and host communities have not yet been postulated. The exploitation and exploration of crude oil and drilling activities generate radioactive waste from naturally occurring radioactive materials and increase radiation exposure to workers and the environment, it is necessary to assess the background ionizing radiation and conduct a radiological impact assessment in these oil fields and their surroundings. The significant amount of waste that has been released from various sources, some of which have the potential to raise NORM levels. Therefore, if these NORMs are not properly monitored, the contaminated environment would spread through various media. Based on the dangers associated with ionizing radiation exposure, particularly from primordial or terrestrial sources, the background ionizing radiation levels in oil fields within the Bayelsa West senatorial district and host communities have not yet been postulated. The exploitation and exploration of crude oil and drilling activities generate radioactive waste from naturally occurring radioactive materials and increase radiation exposure to workers and the environment, it is necessary to assess the background ionizing radiation and conduct a radiological impact assessment in these oil fields and their surroundings. The significant amount of waste that has been released from various sources, some of which have the potential to raise NORM levels. Therefore, if these NORMs are not properly monitored, the contaminated environment would spread through various media.

Several studies on the analysis of naturally occurring radionuclides in soil samples from oil and gas fields have been evaluated to determine their activity concentrations using gamma spectroscopy. Esendu *et al.* (2022) investigated the activity concentration and radium equivalent significance in soil from oil and gas fields in Nembe Communities, Bayelsa State, Nigeria using gamma ray spectrometry. The activity concentrations of (^{40}K, ^{238}U and ^{232}Th) in the studied soil samples in the oil and gas fields had average values as 439.96 ± 24.87 Bqkg^{-1}, 20.82 ± 6.00 Bqkg^{-1} and 49.66 ± 5.23 Bqkg^{-1} respectively. The radium equivalent (Ra_{eq}) was calculated from the activity concentration of radionuclides and was valued at an average of 125.71 Bqkg^{-1} in the study area. The activity concentrations of (^{40}K, ^{238}U and ^{232}Th) and its corresponding radium equivalent (Ra_{eq}) values, when compared with recommended standards where found below the radiological safety limit. In conclusion, the use of the soil for industrial and domestic purposes will not impose any significant threat to human health.

Edomi *et al.*, (2020) carried out a study on the evaluation of radionuclides concentration in Soil and sediment samples from Warri Refinery and Petrochemical Company (WRPC) and Environs in Delta State using NaI (TL) spectrometer. The activity concentration of ^{40}K in soil and sediment samples ranged from 155.22 ± 32.27 to 420.47 ± 1.37 and 425.48 ± 8.43 to 762.09 ± 12.27 ($Bqkg^{-1}$) with average values of 273.83 ± 11.98 and 573.86 ± 9.14 ($Bqkg^{-1}$) respectively. The activity concentration of ^{238}U in soil and sediment samples ranged from 13.19 ± 5.12 to 37.77 ± 2.37 and 36.84 ± 2.26 to 71.42 ± 3.20 ($Bqkg^{-1}$) with an average value of 26.24 ± 3.21 and 46.92 ± 2.28 ($Bqkg^{-1}$) and ^{232}Th had its values ranging from 16.98 ± 2.57 to 36.13 ± 2.53 and 28.42 ± 2.09 to 40.34 ± 1.17 ($Bqkg^{-1}$) averaged at 27.79 ± 3.53 and 36.64 ± 2.21 ($Bqkg^{-1}$) respectively. Mean values obtained for radionuclides were compared with previous literature values from other environments and with global averages. The results show agreement except for the sediment sample mean values, indicating large deviations in radioactivity concentrations in the study area compared to the globally recommended mean values. This is due to oil and gas activity, and uranium is moderately soluble in water. Calculated average values for radiation hazard parameters for soil and sediment samples are below their respective accepted international averages, except for increased lifetime risk of cancer. This is higher than international regulations for both soil and sediment samples.

The radiation exposure of gamma rays, if high is consequential to human health and environment that tends to a number of harmful effects in individuals such as various types of cancer and alteration. When biological and tissues of human are exposed to gamma radiation, it will cause both excitation and ionization in the process altered the structure of the cells and tissues. Therefore, this research work shall aim to evaluate radiological health risks in soil samples in oil and gas producing communities in Bayelsa West Senatorial District.

MATERIALS AND METHOD

Study Area

The research area is the Bayelsa West Senatorial District, which includes the Nigerian local governments of Sagbama and Ekeremor. The area has a total land mass of 2771.9 km^2 and is situated between Latitudes $4^0 42'$N and $5^0 23'$N of the Equator and Longitudes $5^0 23'$E to $6^0 32'$E of the Greenwich Meridian (National Population Commission (NPC), 2009). Yenagoa, Kolokuma/Opokuma and Southern Ijaw LGAs border it to the north by Delta State and to the south. On the Bight of Bonny, the research area also features a coastline that extends for around 60 kilometers. Many of the settlements are unreachable by road since they are partially or entirely surrounded by water. The study areas include a few chosen locations in the Bayelsa West senatorial district (Opukushi, Cloughe Creek, Ofoni, Agbere and Tunu) with a focus on oil and gas installations' mining and exploration zones. Oil and gas can move from one station to another due to interconnected networks of pipes buried in the ground and beneath water. A map showing the studied communities is depicted in figure 1.

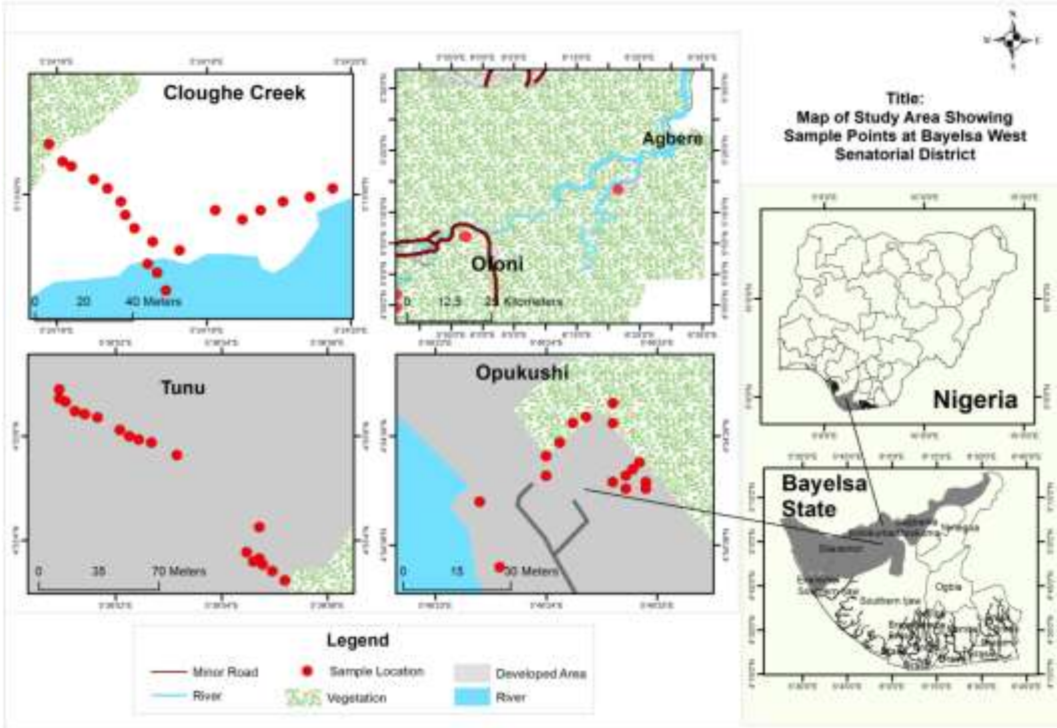

Figure 1: Map of the Study Area Showing Sample Points at Bayelsa West Senatorial district

Samples collection and Preparation

A total number of twenty-five (25) soil samples were collected in the two Local Government Area (Sagbama and Ekeremor Local Government Area), that makes up Bayelsa West Senatorial District. A shovel was used to sample the soils from predetermined depths of 0.5 m to 1.0 m in residential areas, community agricultural areas, and exploratory sites (oil production stations, oil wells) and later being transported to the laboratory for examination, collected soil samples were carefully wrapped in cellophane bags and tagged based on sample location to retain field characteristics. The map of the oil producing communities in Bayelsa West Senatorial District is shown in figure 1. The gamma-ray spectrometry system used for analyzing the samples is Canberra 3 × 3 model 802. The Thallium-activated Sodium Iodide [NaI (Tl)] detector and installed in a 100mm thick lead castle. The detector was connected to an amplifier linked to a computer program GENIE 2 K Window that correlated gamma energies to a number of possible isotopes. The samples were kept in the laboratory under monitoring for thirty (30) days to achieve secular equilibrium. The sample was kept in a marinelli beaker and then was mounted on the NaI (Tl) detector. Shielding from background (environmental) radiation was achieved by counting in Canberra 100 mm thick lead castle. The energy resolution for the detector using Cs-137 from International Atomic Energy Agency (IAEA) is 7.5% at 662KeV Cs-137 line. The energy and efficiency calibration of the system was carried out before sample analysis using the multinuclide reference standard solution supplied by the International Atomic Energy Agency, IAEA. This was to enable identification and quantification of the radionuclides. The standard and the sample were counted for a period of 36,000 seconds to acquire spectral data for a better counting statistics and evaluation. The activity concentration of ^{238}U, ^{232}Th and ^{40}K were determined after correction for background and inhomogeneity was carried out.

Radiological Health Risk Parameters

The radiological health risk parameters were calculated from the primordial radionuclide concentrations of ^{238}U, ^{232}Th and ^{40}K) of the soil samples in the studied communities of Bayelsa West Senatorial District, Bayelsa State. The analysis calculated in the study includes; Radium Equivalent (Ra_{eq}), Absorbed Dose Rate (D), Annual Effective Dose Equivalent(AEDE), Annual Gonadal Equivalent Dose (AGED), Excess Lifetime Cancer Risk (ELCR), Gamma Representative Index (I_{γ}), External Hazard Index (H_{ex}) and Internal Hazard Index (H_{in}) respectively. The estimated results are compared with the world standard value UNSCEAR (2000).

Radium Equivalent (Ra_{eq})

Mathematically described by (Rahman et al., 2008), radium equivalent activity is used to evaluate the risks associated with materials that include ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg. Different radionuclides have different radiation risk weighting factors. For instance, the risk posed by $1Bqkg^{-1}$ of ^{226}Ra is greater than that posed by the comparable radioactive concentration of ^{40}K, but it is lower than that of $1Bqkg^{-1}$ of ^{232}Th. To calculate the total radioactivity, choose the reference radionuclide ^{226}Ra, which is in secular equilibrium with ^{238}U.

This was obtained using the relation below:

$$\mathbf{Ra_{eq}(Bqkg^{-1}) = C_U + 1.43\, C_{Th} + 0.077\, C_K} \qquad (1)$$

Where, C_U, C_{Th} and C_K is the radioactivity concentration in bq/kg of ^{226}Ra, ^{232}Th and ^{40}K respectively.

Absorbed Dose Rate (D)

The amount of energy that ionizing radiation deposits in a medium per unit mass is known as the absorbed dose. It can be expressed in the appropriate SI unit, gray (Gy), or rad, and measured in joules per kilogram. The rate of absorbed dose (D) from the activity concentration of the radionuclides is determined as follows (Tawn, 2002):

$$\mathbf{D = 0.462\, C_U + 0.604\, C_{Th} + 0.0417\, C_K} \qquad (2)$$

Where, D is the absorbed dose rate in $nGyh^{-1}$, C_U, C_{Th} and C_K are the concentrations of Uranium, Thorium and Potassium respectively.

Annual Effective Dose Equivalent (AEDE)

According to Avwiri et al. (2014), the annual effective dosage that a member of the public receives indoors and outdoors is estimated from the absorbed dose rate using a dose conversion factor of 0.7Sv/Gy and occupancy factors of 0.2 and 0.8, respectively. The following formulae are used to calculate AED.

$$\mathbf{AED_{outdoor}(\mu Svy^{-1}) = D(nGyh^{-1}) \times 8760h \times 0.7\ (SvGy^{-1}) \times 0.2 \times 10^{-3}} \qquad \textbf{(3)}$$

In comparison to the default AEDE (indoor), which is 450 Svy^{-1}, the default AEDE (outdoor) is 70 Svy^{-1}. These indices evaluate the likelihood that exposed individuals would experience both probabilistic and deterministic effects (Uyo, 2015).

Annual Gonadal Equivalent Dose (AGED)

Due of their radiation sensitivity, the gonads, bone marrow, and bone surface cells are all listed by UNSCEAR (2000) as organs of interest. The bone marrow is known to be affected by an increase in AGED, which results in the loss of red blood cells and their replacement by white blood cells. Leukemia, a blood malignancy that is lethal, develops because of this circumstance.

The AGED for the resident using such material for building was evaluated by the following equation;

$$\mathbf{AGED\ (mSvy^{-1}) = 3.09C_U + 4.18C_{Th} + 0.314C_K} \qquad \textbf{(4)}$$

Where, C_U, C_{Th} and C_K are the radioactivity concentration of ^{238}U, ^{232}Th and ^{40}K in soil.

Excess Lifetime Cancer Risk (ELCR)

The term "excess lifetime cancer risk" refers to the risk of developing cancer over the course of a lifetime that is greater than the "natural" background risk. In reality, exposure does not last a lifetime, competing causes are prevalent, there are typically multiple carcinogens present in the exposure, and therapy has the potential to significantly lower the chance of dying from cancer.

The following equation (Taskin et al., 2009) is used to determine the Excess Lifetime Cancer Risk (ELCR):

$$\mathbf{ELCR = AEDE \times DL \times RF} \qquad \textbf{(5)}$$

Where, AEDE is the Annual Equivalent Dose Equivalent, DL is the average duration of life (estimated to 70 years), and RF is the Risk Factor(Sv^{-1}), i.e. fatal cancer risk per Sievert. According to Taskin et al. (2009), the ICRP adopts RF as 0.05 for public stochastic effects with 0.29×10^{-3} been the Excess Lifetime Cancer Risk UNSCEAR standard.

Representative Gamma Index (I_γ)

This is used to calculate the risk of gamma radiation posed by the natural radionuclide in particular samples under investigation. According to Avwiri et al. (2014), the representative gamma index was calculated as follows:

$$\mathbf{I_\gamma = \frac{C_U}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \leq 1} \qquad \textbf{(6)}$$

Where, C_U, C_{Th} and C_K are the radioactivity concentration of ^{238}U, ^{232}Th and ^{40}K in soil samples.

Due to the excess external gamma radiation caused by surface material, the I_γ is associated with the annual dosage rate. Greater than the universal standard of unity increases in the representative gamma index may raise the danger of radiation exposure, which could lead to cancer through deforming human cells. According to Avwiri et al. (2014) and Turhan et al. (2008), values of $I_\gamma = 1$ correspond to an annual effective dose of less than or equal to 1 mSv, whereas $I_\gamma = 0.5$ corresponds to an annual effective dose of less than or equal to 0.3 mSv. Thus, materials with $I_\gamma > 1$ should be avoided, and I_γ should only be used as a screening technique to identify materials that may be of concern when utilized as construction materials (Ravisankar et al., 2016). Since the greatest value of the dose rates advised for humans is 1 $mSvy^{-1}$, these values correspond to dose rates higher than that (Avwiri et al., 2014; Turhan et al., 2008; UNSCEAR, 2000).

External and Internal Hazard Indices (H_{ex} and H_{in})

According to the following relations (Ramasamy et al., 2009), the external hazard (H_{ex}) and internal hazard H_{in} hazard indices that reflect external exposure and internal exposure, respectively, are evaluated as follows;

$$\mathbf{H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1} \qquad \textbf{(7)}$$

$$\mathbf{H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810}} < 1 \qquad \textbf{(8)}$$

RESULTS AND DISCUSSION

Results

The result of the primordial radionuclide concentrations of (^{238}U, ^{232}Th and ^{40}K) of the soil samples and their corresponding Radium Equivalent (Ra_{eq}), in the studied communities of Bayelsa West Senatorial District, Bayelsa State are presented in Table 1 to Table 5. Table 6 shows the Calculated Average Specific Activity Concentration of Radionuclides and Corresponding Radium Equivalent in Soil Samples collected from Selected Oil Producing Communities in Bayelsa West Senatorial District, Bayelsa State while Table 7 represents the comparison of the average activity concentrations of radionuclides in soil in the current study to other parts. The calculated radiological health risk parameters are presented in Table 8 to Table .

Figure 2 to Figure 5 show the comparison of activity concentration of ^{238}U, ^{232}Th, ^{40}K and Ra_{eq} in soil samples of the studied area with UNSCEAR, (2000). Figure 6 to Figure 12 shows the Comparison of the radiological health risk parameters in the studied oil producing communities versus the World Safety limit (UNSCEAR, 2000).

Table 1: Specific Activity Concentration of Radionuclides and Corresponding Radium Equivalent in Soil Samples collected from Opukushi Community in Bayelsa West Senatorial District, Bayelsa State

S/N	GPS Point	Sample code	^{40}K ($Bqkg^{-1}$)	^{238}U ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	Ra_{eq} ($Bqkg^{-1}$)
1	$N04^0 54.630'$ $E005^0 46.393'$	1A	382.05 ± 20.43	23.50 ± 3.59	8.87 ± 0.55	65.60
2	$N04^0 54.649'$ $E005^0 46.402'$	1B	678.41 ± 36.15	19.69 ± 3.07	11.91 ± 0.74	88.96
3	$N04^0 54.647'$ $E005^0 46.413'$	1C	620.94 ± 32.81	11.91 ± 2.39	6.42 ± 0.40	68.90
4	$N04^0 54.642'$ $E005^0 46.412'$	1D	546.93 ± 28.90	14.60 ± 2.34	8.81 ± 0.55	69.31
5	$N04^0 54.640'$ $E005^0 46.390'$	1E	526.17 ± 27.90	22.16 ± 3.34	11.48 ± 0.71	79.09
Mean			$\mathbf{522.190 \pm 169.753}$	$\mathbf{18.372 \pm 4.959}$	$\mathbf{11.134 \pm 2.412}$	$\mathbf{74.372 \pm 9.586}$

Table 2: Specific Activity Concentration of Radionuclides in Soil and Corresponding Radium Equivalent in Soil Samples collected from Cloughe Creek Community in Bayelsa West Senatorial District, Bayelsa State

S/N	GPS Point	Sample code	^{40}K ($Bqkg^{-1}$)	^{238}U ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	Ra_{eq} ($Bqkg^{-1}$)
1	$N04^0 51.371'$ $E005^0 41.536'$	2A	655.85 ± 34.80	26.04 ± 4.31	9.21 ± 0.57	89.71

2	$N04^0 51.381'$ $E005^0 41.526'$	2B	339.02 ± 18.31	19.61 ± 3.29	10.07 ± 0.63	60.11
3	$N04^0 51.400'$ $E005^0 41.529'$	2C	342.33 ± 18.32	8.17 ± 1.59	10.56 ± 0.66	49.63
4	$N04^0 51.416'$ $E005^0 41.543'$	2D	631.78 ± 33.28	23.20 ± 3.80	8.87 ± 0.55	84.53
5	$N04^0 51.420'$ $E005^0 41.543'$	2E	314.35 ± 16.95	19.61 ± 3.31	10.07 ± 0.62	58.22
Mean			$\mathbf{456.666 \pm 171.396}$	$\mathbf{19.326 \pm 6.795}$	$\mathbf{9.756 \pm 0.694}$	$\mathbf{68.440 \pm 17.599}$

Table 3: Specific Activity Concentration of Radionuclides and Corresponding Radium Equivalent in Soil Samples collected from Ofoni Community in Bayelsa West Senatorial District, Bayelsa State

S/N	**GPS Point**	**Sample code**	**^{40}K ($Bqkg^{-1}$)**	**^{238}U ($Bqkg^{-1}$)**	**^{232}Th ($Bqkg^{-1}$)**	**Ra_{eq} ($Bqkg^{-1}$)**
1	$N05^0 06.088'$ $E005^0 57.459'$	3A	882.70 ± 46.24	4.81 ± 0.98	14.58 ± 0.90	93.63
2	$N05^0 06.084'$ $E005^0 57.458'$	3B	1038.69 ± 49.85	36.33 ± 2.72	17.00 ± 0.95	140.62
3	$N05^0 06.080'$ $E005^0 57.452'$	3C	468.40 ± 24.88	23.88 ± 3.85	6.75 ± 0.42	66.70
4	$N05^0 06.065'$ $E005^0 57.456'$	3D	598.38 ± 31.24	42.57 ± 5.20	10.62 ± 0.66	103.83
5	$N05^0 06.059'$ $E005^0 57.475'$	3E	342.64 ± 18.59	10.27 ± 1.76	5.55 ± 0.35	44.59
Mean			$\mathbf{666.162 \pm 288.979}$	$\mathbf{23.572 \pm 16.233}$	$\mathbf{10.900 \pm 4.916}$	$\mathbf{88.874 \pm 36.646}$

Table 4: Specific Activity Concentration of Radionuclides in and Corresponding Radium Equivalent in Soil Samples collected from Agbere Community in Bayelsa West Senatorial District, Bayelsa State

S/N	**GPS Point**	**Sample code**	**^{40}K ($Bqkg^{-1}$)**	**^{238}U ($Bqkg^{-1}$)**	**^{232}Th ($Bqkg^{-1}$)**	**Ra_{eq} ($Bqkg^{-1}$)**
1	$N05^0 13.663'$ $E005^0 24.302'$	4A	537.60 ± 28.74	5.63 ± 1.19	8.78 ± 0.54	59.58
2	$N05^0 13.649'$ $E005^0 24.289'$	4B	605.60 ± 32.19	20.16 ± 3.41	5.89 ± 0.37	75.21

3	N05⁰13.645′ E005⁰24.291′	4C	1017.50 ± 52.76	29.71 ± 4.23	20.45 ± 1.25	137.30
4	N05⁰13.668′ E005⁰24.328′	4D	576.71 ± 30.70	35.69 ± 4.63	15.97 ± 0.99	102.93
5	N05⁰13.659′ E005⁰24.284′	4E	397.09 ± 21.34	13.85 ± 2.42	27.61 ± 1.67	83.91
Mean			**626.900 ± 232.555**	**20.900 ± 11.943**	**15.740 ± 8.783**	**91.786 ± 29.874**

Table 5: Specific Activity Concentration of Radionuclides in Soil and Corresponding Radium Equivalent in Soil Samples collected from Tunu Community in Bayelsa West Senatorial District, Bayelsa State

S/N	GPS Point	Sample code	^{40}K ($Bqkg^{-1}$)	^{238}U ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	(Ra_{eq}) $Bqkg^{-1}$
1	N04⁰53.054′ E005⁰36.920′	5A	421.77 ± 22.86	19.84 ± 3.19	5.58 ± 0.35	60.30
2	N04⁰53.057′ E005⁰36.916′	5B	307.73 ± 16.52	18.34 ± 3.12	9.67 ± 0.60	55.86
3	N04⁰53.112′ E005⁰36.851′	5C	504.81 ± 26.92	*BDL*	20.48 ± 1.25	68.16
4	N04⁰53.106′ E005⁰36.864′	5D	291.49 ± 15.64	4.28 ± 0.99	10.99 ± 0.68	42.44
5	N04⁰53.094′ E005⁰36.886′	5E	136.84 ± 7.52	9.07 ± 1.71	2.20 ± 0.14	22.75
Mean			**332.528 ± 139.855**	**10.306 ± 8.653**	**9.784 ± 6.911**	**49.902 ± 17.818**

Table 6: The Calculated Average Specific Activity Concentration of Radionuclides and Corresponding Radium Equivalent in Soil Samples collected from Selected Oil Producing Communities in Bayelsa West Senatorial District, Bayelsa State

S/N	Location	^{40}K ($Bqkg^{-1}$)	^{238}U ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	Ra_{eq} ($Bqkg^{-1}$)
1	Opukushi	522.190 ± 169.753	18.372 ± 4.959	11.134 ± 2.412	74.372 ± 9.586
2	Cloughe Creek	456.666 ± 171.396	19.326 ± 6.795	9.756 ± 0.694	68.440 ± 17.599
3	Ofoni	666.162 ± 288.979	23.572 ± 16.233	10.900 ± 4.916	88.874 ± 36.646
4	Agbere	626.900 ± 232.555	20.900 ± 11.943	15.740 ± 8.783	91.786 ± 29.874

5	Tunu	332.528 ± 139.855	10.306 ± 8.653	9.784 ± 6.911	49.902 ± 17.818
	World Average (UNSCEAR, 2000)	**420**	**33**	**45**	**370**

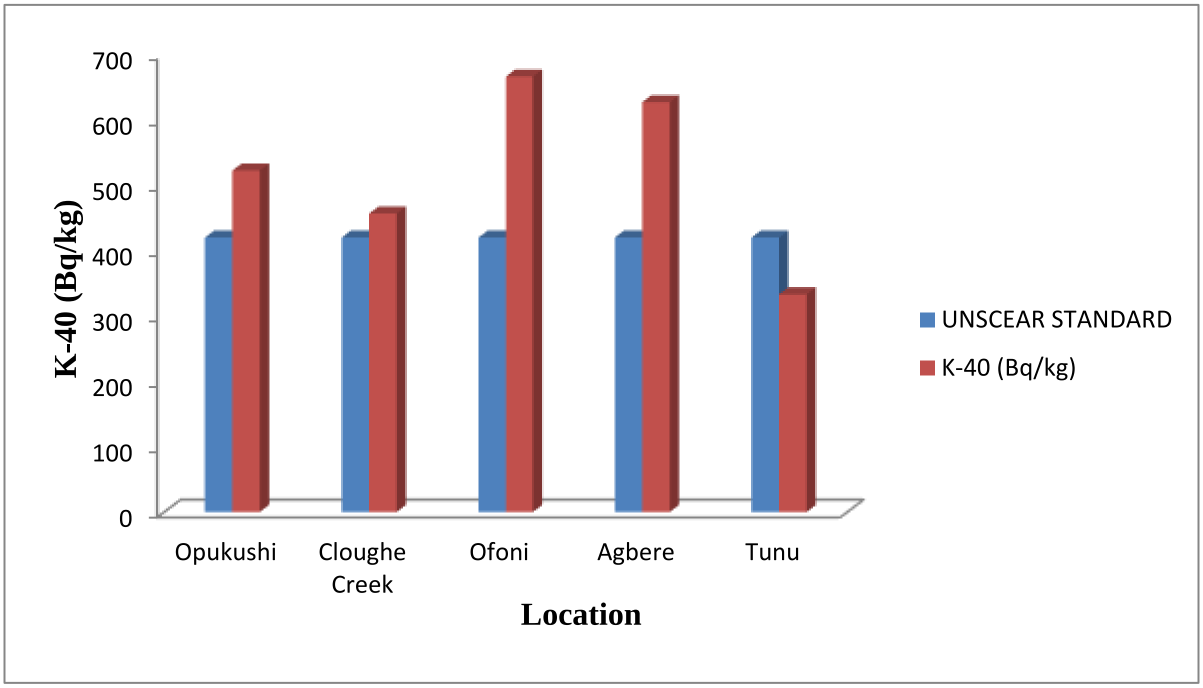

Figure 2: Comparison of ^{40}K in the different studied communities in the study area with the world's recommended limit (UNSCEAR, 2000).

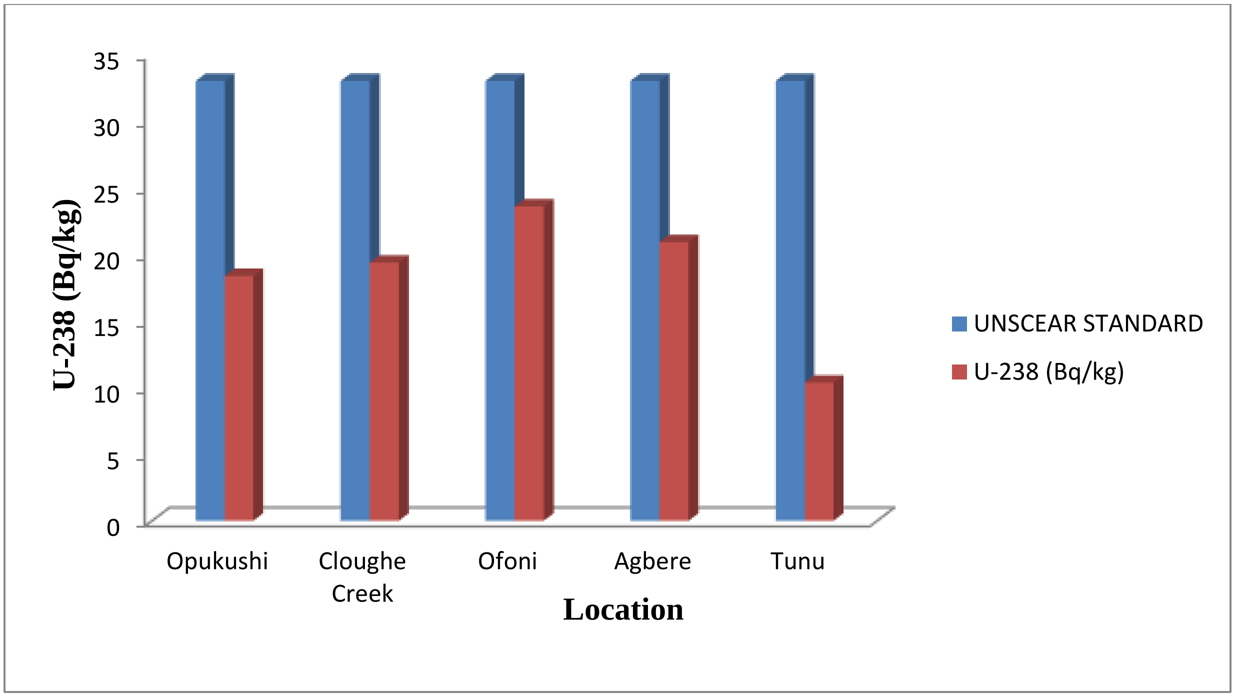

Figure 3: Comparison of ^{238}U in the different studied communities in the study area with the world's recommended limit (UNSCEAR, 2000).

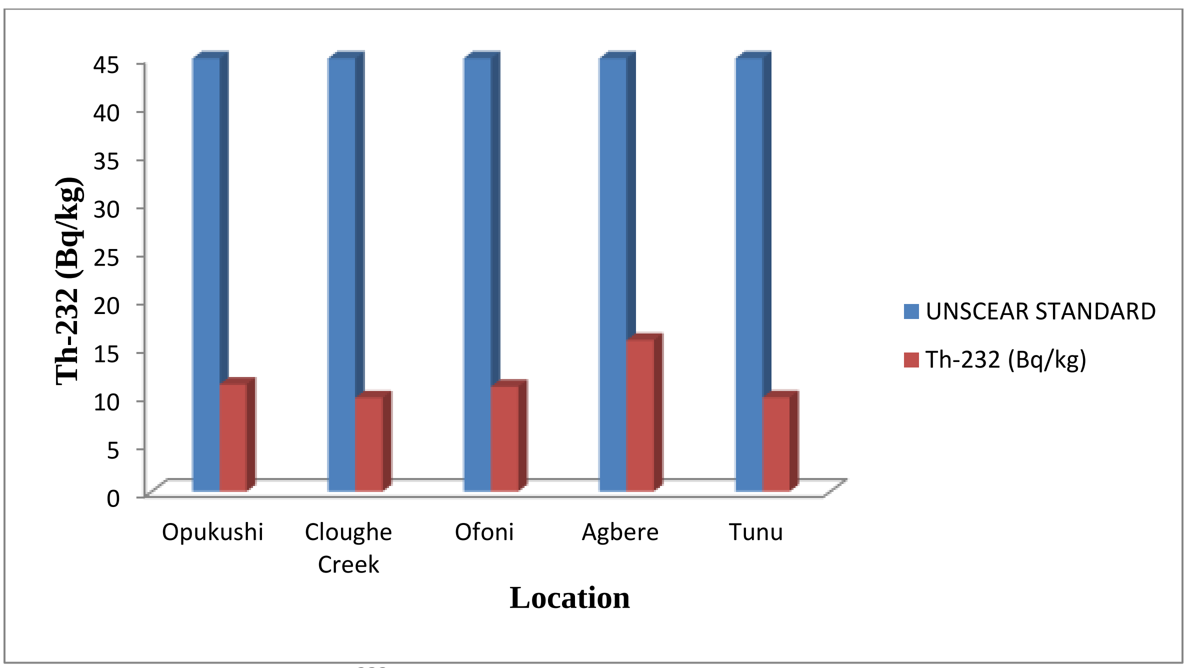

Figure 4: Comparison of ^{232}Th in the different studied communities in the study area with the world's recommended limit (UNSCEAR, 2000).

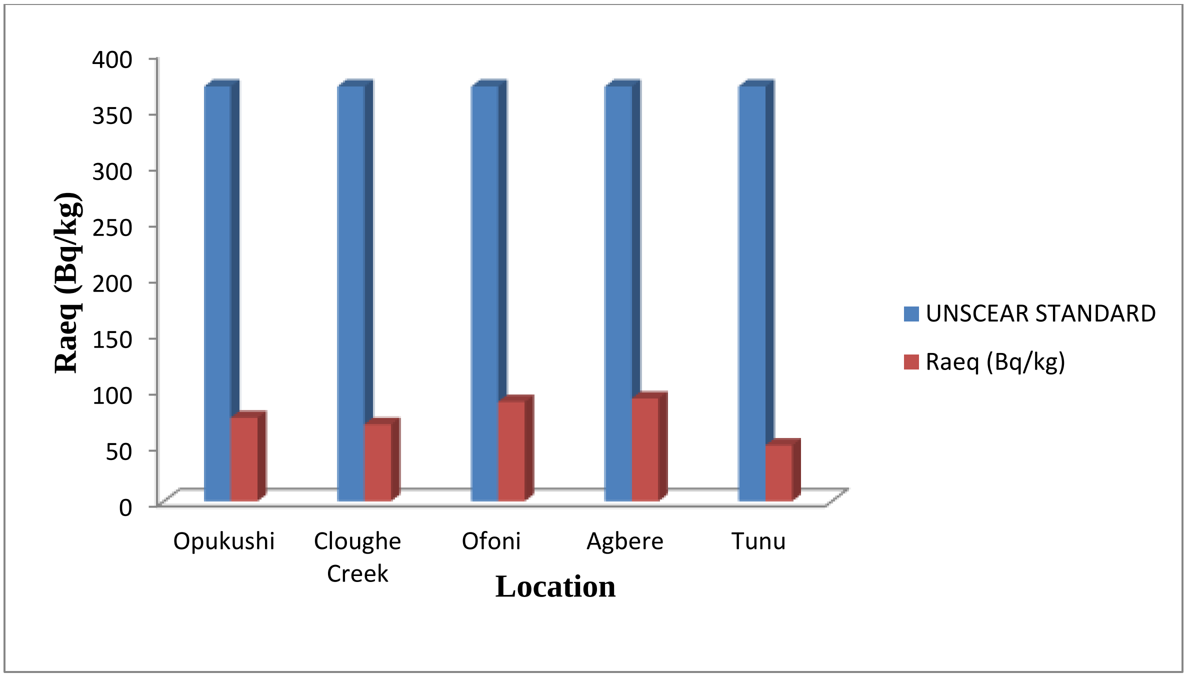

Figure 5: Comparison of Ra_{eq} in the different studied communities in the study area with the world's recommended limit (UNSCEAR, 2000)

Table 7: Comparison of the average activity concentrations of radionuclides in the current study to other parts of the world

Country	$^{40}K(\mathbf{Bqkg}^{-1})$	$^{238}U(\mathbf{Bqkg}^{-1})$	$^{232}Th(\mathbf{Bqkg}^{-1})$	References	Sample type
Nigeria	439.96 ± 24.87	20.82 ± 6.00	49.66 ± 5.23	Esendu et al., 2022	Soil
Iraq	213.71 ± 8.896	19.80 ± 0.0948	13.65 ± 1.012	Zainab et al., 2022	Soil
Egypt	21.00 ± 1.5	25.00 ± 1.3	26.10 ± 1.0	Khaled et al., 2021	Crude oil
Syria	198.21 ± 80.52	1939.56 ± 997.46	737.86 ± 410.94	Desouky et al., 2021	Soil
Bangladesh	449	21	40	Mohammed et al., 2020	Soils & solid wastes
Saudi Arabia	278.80 ± 9.8	39.04 ± 4.8	7.73 ± 1.2	Alshahri et al., 2019	Soil
Iraq	480.33	19.90	20.06	Karwan et al., 2021	Sludge and soil
Gabon	355.00 ± 93.00	2811.00 ± 198.00	63.00 ± 12.00	Mouandza et al., 2018	Soil

Nigeria	522.190 ± 169.753	18.372 ± 4.959	11.134 ± 2.412	Present study	Soil
Nigeria	456.666 ± 171.396	19.326 ± 6.795	9.756 ± 0.694	Present study	Soil
Nigeria	666.162 ± 288.979	23.572 ± 16.233	10.900 ± 4.916	Present study	Soil
Nigeria	626.900 ± 232.555	20.900 ± 11.943	15.740 ± 8.783	Present study	Soil
Nigeria	332.528 ± 139.855	10.306 ± 8.653	9.784 ± 6.911	Present study	Soil

Table 8: Calculated Radiological Health Risk Parameters from Activity Concentration of Primordial Radionuclides in Soil Samples of Opukushi Community in Bayelsa West Senatorial District, Bayelsa State

S/N	Location	Code	D ($nGyh^{-1}$)	AEDE (μSvy^{-1})	AGED ($mSvy^{-1}$)	ELCR $\times 10^{-3}$	I_γ	H_{ex}	H_{in}
1	Opukushi	1A	31.12	38.17	229.66	0.14	0.50	0.18	0.24
2	Opukushi	1B	44.58	54.67	323.65	0.19	0.70	0.24	0.23
3	Opukushi	1C	35.20	43.17	258.61	0.15	0.56	0.19	0.22
4	Opukushi	1D	34.86	42.75	253.68	0.15	0.55	0.19	0.23
5	Opukushi	1E	39.15	48.01	281.68	0.17	0.61	0.21	0.27
	Mean		$\mathbf{36.98 \pm 5.111}$	$\mathbf{45.35 \pm 6.265}$	$\mathbf{269.46 \pm 35.485}$	$\mathbf{0.16 \pm 0.020}$	$\mathbf{0.58 \pm 0.757}$	$\mathbf{0.20 \pm 0.024}$	$\mathbf{0.24 \pm 0.192}$

Table 9: Calculated Radiological Health Risk Parameters from Activity Concentration of Primordial Radionuclides in Soil Samples of Cloughe Creek Community in Bayelsa West Senatorial District, Bayelsa State

S/N	Location	Code	D ($nGyh^{-1}$)	AEDE (μSvy^{-1})	AGED ($mSvy^{-1}$)	ELCR $\times 10^{-3}$	I_γ	H_{ex}	H_{in}
1	Cloughe Creek	2A	44.89	55.05	324.90	0.19	0.70	0.24	0.35
2	Cloughe Creek	2B	29.35	35.99	209.14	0.13	0.46	0.16	0.22

3	Cloughe Creek	2C	24.52	30.07	176.88	0.11	0.39	0.13	0.16
4	Cloughe Creek	2D	42.38	51.97	307.14	0.18	0.66	0.23	0.29
5	Cloughe Creek	2E	28.33	34.74	201.39	0.12	0.44	0.16	0.16
	Mean		**33.89 ± 9.116**	**41.56 ± 11.179**	**243.89 ± 67.207**	**0.15 ± 0.036**	**0.53 ± 0.140**	**0.18 ± 0.048**	**0.24 ± 0.083**

Table 10: Calculated Radiological Health Risk Parameters from Activity Concentration of Primordial Radionuclides in Soil Samples of Ofoni Community in Bayelsa West Senatorial District, Bayelsa State

S/N	Location	Code	D ($nGyh^{-1}$)	AEDE (μSvy^{-1})	AGED ($mSvy^{-1}$)	ELCR $\times 10^{-3}$	I_γ	H_{ex}	H_{in}
1	Ofoni	3A	47.84	58.67	352.98	0.21	0.77	0.25	0.27
2	Ofoni	3B	70.34	86.26	509.47	0.30	1.10	0.38	0.48
3	Ofoni	3C	34.61	42.45	249.08	0.15	0.54	0.28	0.34
4	Ofoni	3D	51.01	62.56	363.82	0.22	0.79	0.28	0.40
5	Ofoni	3E	22.38	27.45	162.52	0.10	0.35	0.12	0.16
	Mean		**45.24 ± 18.067**	**55.48 ± 22.154**	**327.57 ± 130.814**	**0.20 ± 0.757**	**0.71 ± 0.283**	**0.26 ± 0.093**	**0.33 ± 0.122**

Table 11: Calculated Radiological Health Risk Parameters from Activity Concentration of Primordial Radionuclides in Soil Samples of Agbere Community in Bayelsa West Senatorial District, Bayelsa State

S/N	Location	Code	D($nGyh^{-1}$)	AEDE (μSvy^{-1})	AGED ($mSvy^{-1}$)	ELCR $\times 10^{-3}$	I_γ	H_{ex}	H_{in}
1	Agbere	4A	30.32	37.18	222.90	0.13	0.48	0.16	0.18
2	Agbere	4B	38.04	46.65	277.07	0.16	0.60	0.20	0.28
3	Agbere	4C	68.56	84.08	496.78	0.29	1.08	0.37	0.45
4	Agbere	4D	50.28	61.66	358.12	0.22	0.78	0.27	0.37
5	Agbere	4E	40.03	49.09	282.89	0.17	0.63	0.23	0.26
	Mean		**45.45 ± 14.753**	**55.73 ± 18.094**	**327.55 ± 106.146**	**0.19 ± 0.063**	**0.71 ± 0.231**	**0.25 ± 0.081**	**0.31 ± 0.104**

Table 12: Calculated Radiological Health Risk Parameters from Activity Concentration of Primordial Radionuclides in Soil Samples of Tunu Community in Bayelsa West Senatorial District, Bayelsa State

S/N	Location	Code	D ($nGyh^{-1}$)	AEDE (μSvy^{-1})	AGED ($mSvy^{-1}$)	ELCR $\times 10^{-3}$	I_γ	H_{ex}	H_{in}
1	Tunu	5A	30.08	36.89	217.07	0.13	0.47	0.16	0.22
2	Tunu	5B	27.22	33.38	193.72	0.12	0.42	0.15	0.20
3	Tunu	5C	33.66	41.28	244.11	0.14	0.54	0.18	0.18
4	Tunu	5D	20.89	25.62	150.69	0.09	0.33	0.11	0.13
5	Tunu	5E	11.22	13.76	80.19	0.05	0.46	0.09	0.12
	Mean		$\mathbf{24.61 \pm 8.828}$	$\mathbf{30.19 \pm 10.827}$	$\mathbf{177.16 \pm 64.135}$	$\mathbf{0.11 \pm 0.037}$	$\mathbf{0.44 \pm 0.077}$	$\mathbf{0.14 \pm 0.037}$	$\mathbf{0.17 \pm 0.436}$

Table 13: Calculated Mean of Radiological Health Risk Parameters from Activity Concentration of Primordial Radionuclides in Soil Samples of Oil Producing Communities in Bayelsa West Senatorial District, Bayelsa State

S/N	Location	D ($nGyh^{-1}$)	AEDE (μSvy^{-1})	AGED ($mSvy^{-1}$)	ELCR $\times 10^{-3}$	I_γ	H_{ex}	H_{in}
1	Opukushi	36.98 ± 5.111	45.35 ± 6.265	269.46 ± 35.485	0.16 ± 0.020	0.58 ± 0.757	0.20 ± 0.024	0.24 ± 0.192
2	Clough Creek	33.89 ± 9.116	41.56 ± 11.179	243.89 ± 67.207	0.15 ± 0.036	0.53 ± 0.140	0.18 ± 0.048	0.24 ± 0.083
3	Ofoni	45.24 ± 18.067	55.48 ± 22.154	327.57 ± 130.814	0.20 ± 0.757	0.71 ± 0.283	0.26 ± 0.093	0.33 ± 0.122
4	Agbere	45.45 ± 14.753	55.73 ± 18.094	327.55 ± 106.146	0.19 ± 0.063	0.71 ± 0.231	0.25 ± 0.081	0.31 ± 0.104
5	Tunu	24.61 ± 8.828	30.19 ± 10.827	177.16 ± 64.135	0.11 ± 0.037	0.44 ± 0.077	0.14 ± 0.037	0.17 ± 0.436
	Mean	$\mathbf{37.23 \pm 8.692}$	$\mathbf{45.66 \pm 10.654}$	$\mathbf{269.13 \pm 63.095}$	$\mathbf{0.16 \pm 0.036}$	$\mathbf{0.59 \pm 0.117}$	$\mathbf{0.21 \pm 0.049}$	$\mathbf{0.26 \pm 0.064}$
	UNSCEAR, 2000	84	70	300	0.29×10^{-3}	1	1	1

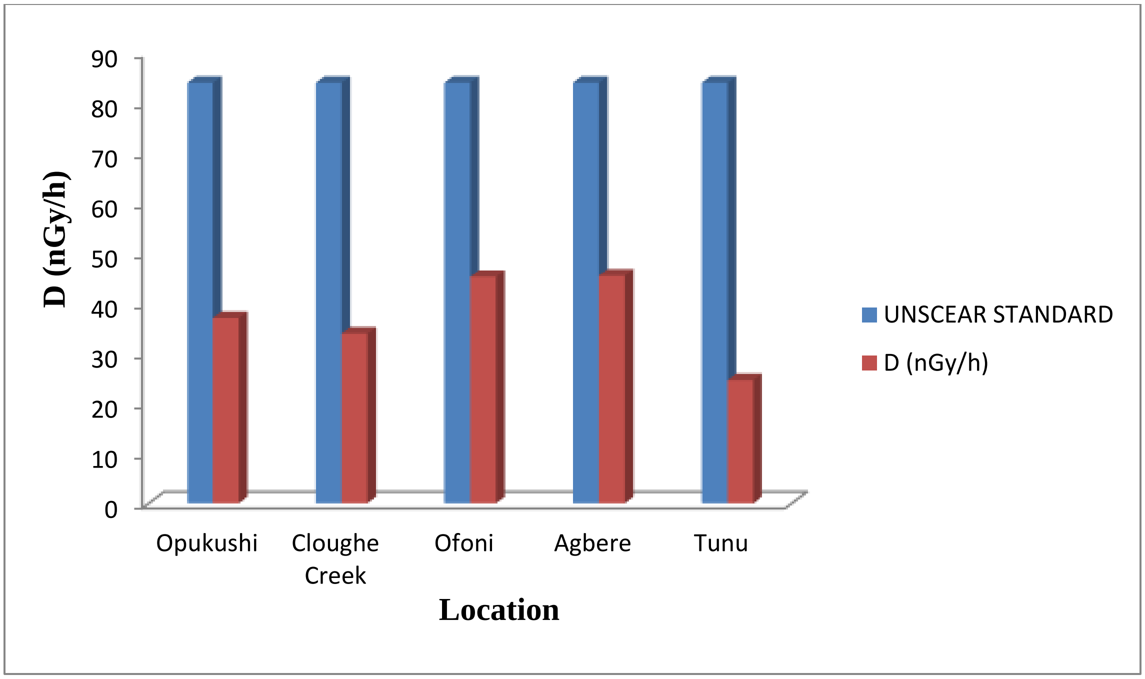

Figure 6: Comparison of the Absorbed Dose Rate (D) in the studied oil producing communities versus the World Safety limit (UNSCEAR, 2000).

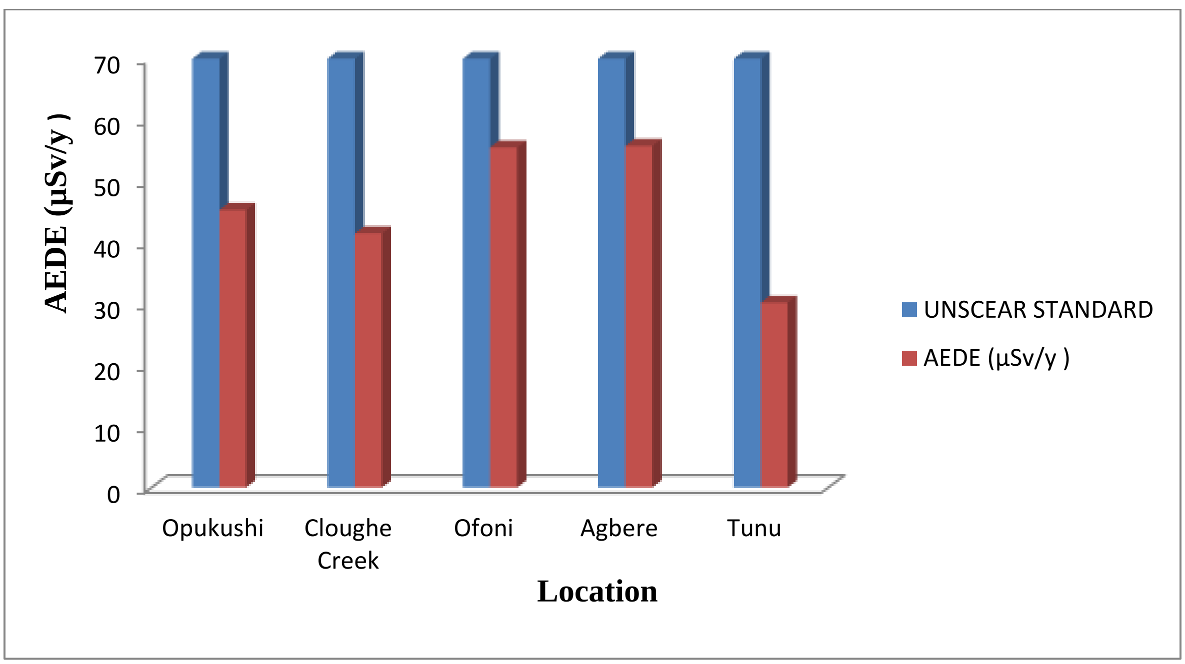

Figure 7: Comparison of the Annual Effective Dose Equivalent (AEDE) in the studied oil producing communities versus the World Safety limit (UNSCEAR, 2000)

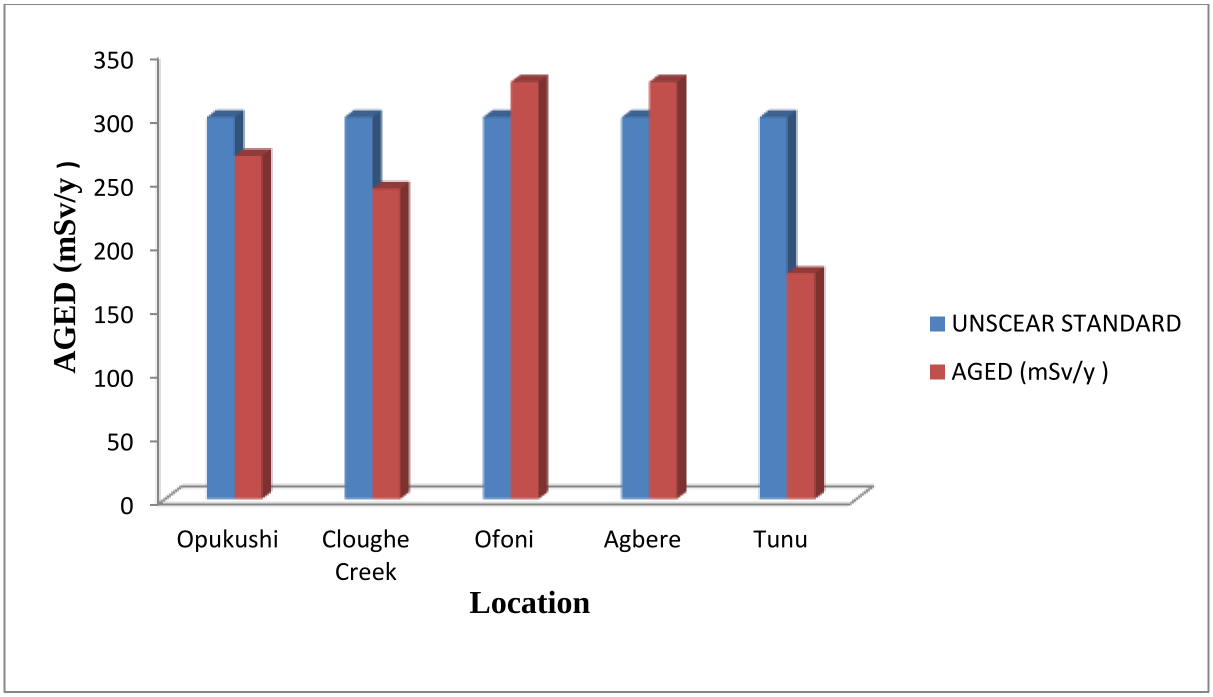

Figure 8: Comparison of the Annual Gonadal Equivalent Dose (AGED) in the studied oil producing communities versus the World Safety limit (UNSCEAR, 2000)

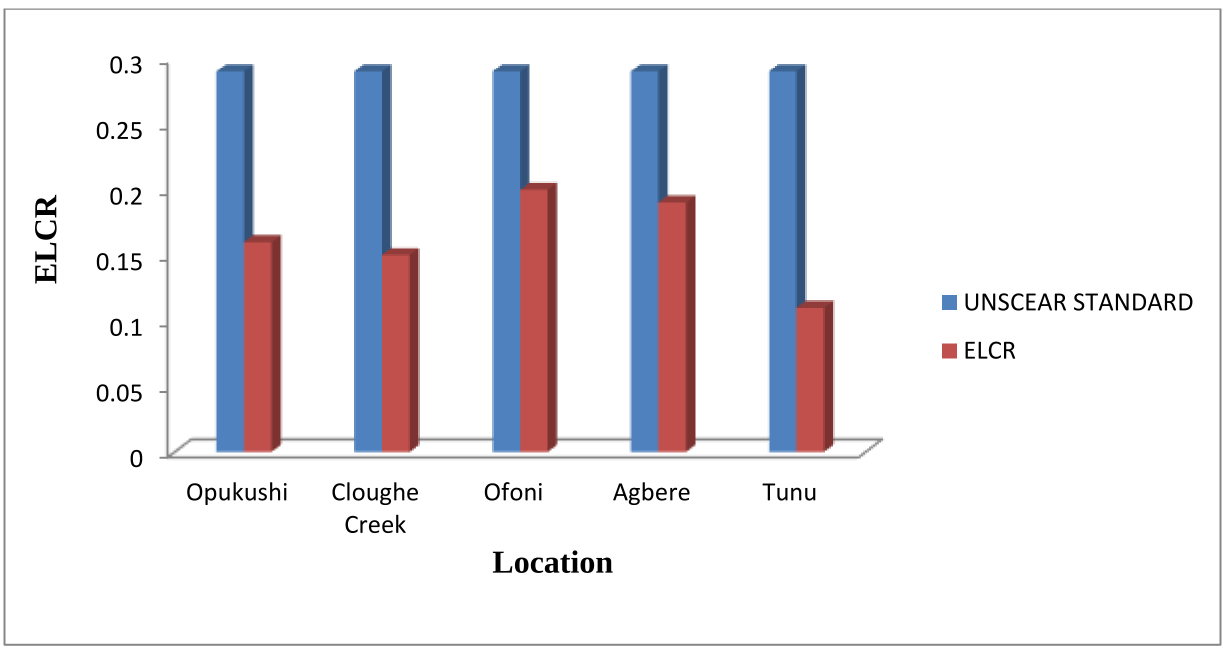

Figure 9: Comparison of the Excess Lifetime Cancer Risk (ELCR) in the studied oil producing communities versus the World Safety limit (UNSCEAR, 2000).

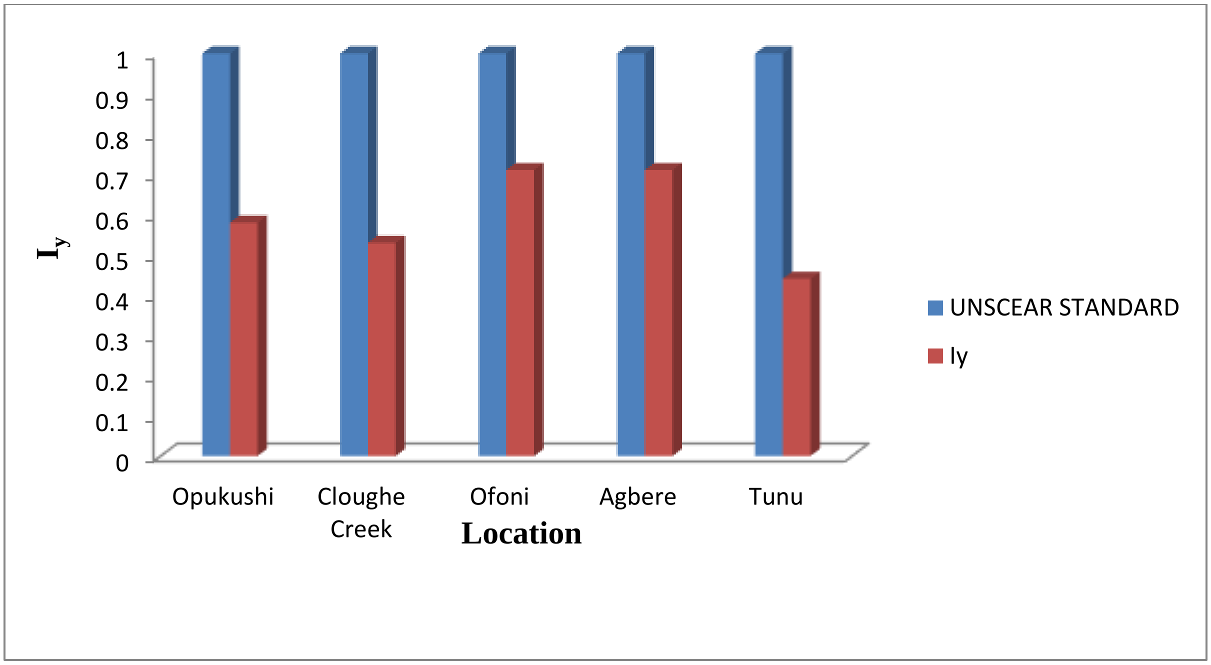

Figure 10: Comparison of the Gamma Representative Index (I_y) in the studied oil producing communities versus the World Safety limit (UNSCEAR, 2000)

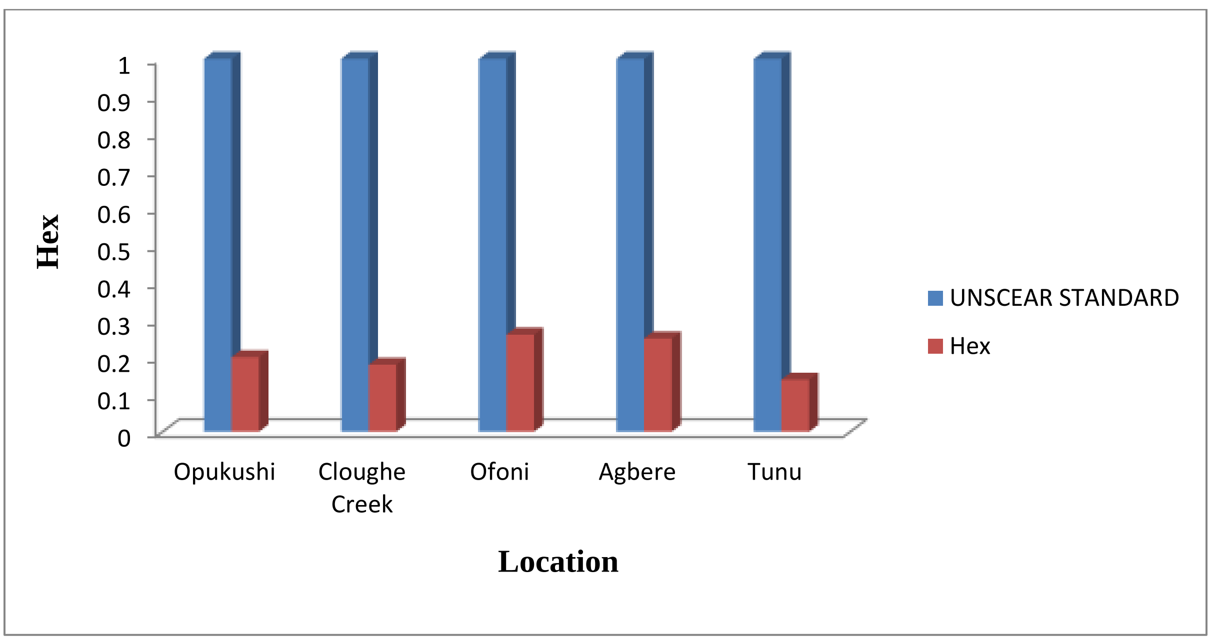

Figure 11: Comparison of the External Hazard Index (H_{ex}) in the studied oil producing communities versus the World Safety limit (UNSCEAR, 2000)

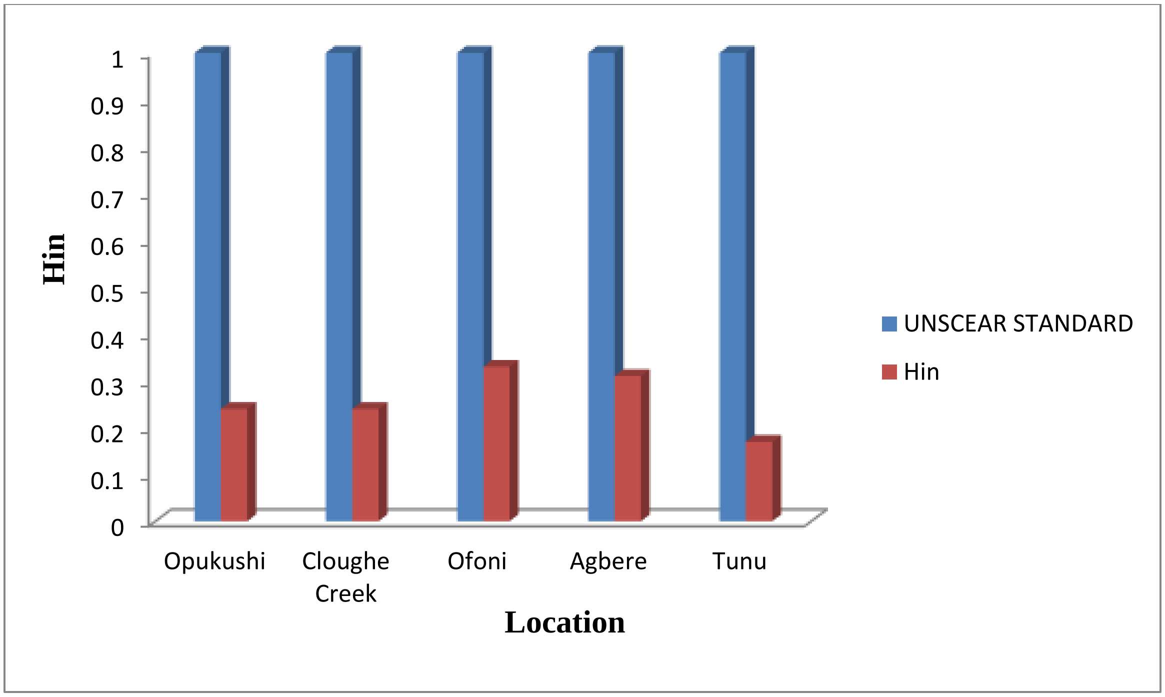

Figure 12: Comparison of the Internal Hazard Index (H_{in}) in the studied oil producing communities versus the World Safety limit (UNSCEAR, 2000)

Discussion

The results of the mean activity concentration of naturally occurring primordial radionuclides of ^{40}K, ^{238}U and ^{232}Th and their corresponding Radium Equivalent (Ra_{eq}) evaluated in oil producing communities in Bayelsa West Senatorial District, Bayelsa State, Nigeria and their radium equivalent (Ra_{eq}) values are presented in Table 1. The average values of the mean activity concentration of ^{40}K ranged from 332.528 ± 139.855 $Bqkg^{-1}$ (Tunu) to 666.162 ± 288.979 $Bqkg^{-1}$ (Ofoni) with an overall average of 520.888 ± 134.119 $Bqkg^{-1}$. The average activity concentration of ^{238}U in soil samples of the studied areas have its minimum value as 10.306 ± 8.653 $Bqkg^{-1}$ at Tunu community and have its maximum average value as 23.572 ± 16.233 $Bqkg^{-1}$ at Ofoni Community with an overall mean of 18.495 ± 4.983 $Bqkg^{-1}$. The estimated average values of the activity concentration of ^{232}Th have its minimum value as 9.756 ± 0.694 $Bqkg^{-1}$ at Cloughe Creek community and its maximum value as 11.134 ± 2.412 $Bqkg^{-1}$ at Opukushi community with an overall mean value of 11.463 ± 2.472 $Bqkg^{-1}$. In comparing the deduced mean results of soil samples of ^{40}K, ^{238}U and ^{232}Th with the standard permissible limits (UNSCEAR, 2000), the following deductions were made. The mean average value of ^{40}K at Tunu was greater than the permissible limit of $400 Bqkg^{-1}$, while values for ^{238}U and ^{232}Th were below the permissible limit of $33\ Bqkg^{-1}$ and $35\ Bqkg^{-1}$ (UNSCEAR, 2000) respectively. The estimated mean values of Ra_{eq} in the studied communities are all below the recommended standard limit of $370\ Bqkg^{-1}$. The anomalous elevated value of activity concentration of ^{40}K in the study area may be pointed to the oil and gas exploration activities which may had resulted to oil spillage, oil bunkering and drilling activities carried out across the entire study area (Avwiri et al., 2017; Ovuomarie et al., 2018). The activity concentration of ^{40}K, ^{238}U and ^{232}Th of soil samples in the studied area have been compared with related works in Nigeria and other parts of the world and the summarized data are presented in Table 2 correspondingly. The ^{40}K data obtained in the studied area was higher than reported soil samples in Nigeria (439.96 ± 24.87 Bqkg^{-1}), Iraq (213.71 ± 8.896 Bqkg^{-1}), Egypt (21.00 ± 1.5 Bqkg^{-1}), Syria (198.21 ± 80.52 Bqkg^{-1}), Bangladesh (449 Bqkg^{-1}), Saudi Arabia (278.80 ± 9.8 Bqkg^{-1}), Iraq (480.33 Bqkg^{-1}) and Gabon (355.00 ± 93.00 Bqkg^{-1}). It was also noticed that the mean value of activity concentration of ^{238}U was lower than the estimated values reported in Egypt (25.00 ± 1.3Bqkg^{-1}), Syria (1939.56 ± 997.46 Bqkg^{-1}), Saudi Arabia (39.04 ± 4.8Bqkg^{-1}) and Gabon (2811.00 ± 198.00 Bqkg^{-1}). The comparison of the mean value of ^{232}Th of soil samples in the studied area with other studies showed that the values were below the reported values in Nigeria (49.66 ± 5.23Bqkg^{-1}), Egypt (26.10 ± 1.0Bqkg^{-1}), Syria (737.86 ± 410.94Bqkg^{-1}), Bangladesh (40Bqkg^{-1}), Iraq (20.06Bqkg^{-1}) and Gabon (63.00 ± 12.00Bqkg^{-1}). The difference in the activity concentration of the radioactivity levels in soil in different localities of the world depend on the geographical and geology conditions of the area and the agricultural lands were fertilizers was employed in large extent in the course of farming.

The mean values of Radium Equivalent (Ra_{eq}) in the studied area calculated from activity concentration of ^{40}K, ^{238}U, ^{232}Th ranged from 49.902 ± 17.818 Bqkg^{-1} (Tunu) to 88.874 ± 36.646 Bqkg^{-1} (Ofoni). From observation, the oil and gas producing communities Radium Equivalent (Ra_{eq}) values were lower than the standard limit of 300 Bqkg^{-1} (UNSCEAR, 2000). Furthermore, based on the calculated values of Ra_{eq} in the study area agricultural activities are encouraged to be engaged and the soil is recommendable for building and construction of houses, since it does not pose any radiological risk to human.

The result of radiological health risk parameters calculated from the activity concentration of primordial radionuclide (^{40}K, ^{238}U and ^{232}Th) are presented in Table 3.

The calculated results of the absorbed dose rate (D) from soil samples ranged from 24.61 ± 8.828 nGy^{-1} (Tunu) to 45.45 ± 14.753 nGyh^{-1}(Agbere) with an overall mean value of 37.23 ± 8.692 nGyh^{-1}. When compared with Avwiri et al. (2015) value of 103.49 nGyh^{-1} and Esendu et al. (2022) value of 60.5 nGyh^{-1}, the value of the study area is below their study. In addition, the value of absorbed dose rate in the study area is far below the permissible the permissible limit of 84 nGy^{-1} (UNSCEAR, 2000) and poses no threat on the environment and oil and gas workers. The Annual Effective Dose Equivalent (AEDE) ranged from 30.19 ± 10.827 μSvy^{-1}(Tunu) to 55.73 ± 18.094 μSvy^{-1} with an overall mean value of 45.66 ± 10.654 μSvy^{-1}. The value is lower than the world standard value of 70 μSvy^{-1}. The estimated result for Annual Gonadal Equivalent Dose (AGED) 177.16 ± 64.135 mSvy^{-1} to 327.55 ± 106.146 mSvy^{-1} with an overall average value of 269.13 ± 63.095 mSvy^{-1}. The estimated value was higher than the value of 137.02 mSvy^{-1} Iwetan et al. (2015) and lower than the recommended safety limit of 300 mSvy^{-1} UNSCEAR (2000). The values for Excess Lifetime Cancer Risk (ELCR) varied from $0.11 \times 10^{-3} \pm 0.037$ to $0.20 \times 10^{-3} \pm 0.757$ with an average value of $0.16 \times 10^{-3} \pm 0.036$ The result of the study area when compared with Esendu et al. (2022) value of 0.19×10^{-3} was consistent and also below the standard value of 0.29×10^{-3} (UNSCEAR, 2000). It implies that the probability of contracting cancer by those living within the study area is not high, since it poses no threat. The representative gamma index (I_{γ}) varied from 0.44 ± 0.077 (Tunu) to 0.71 ± 0.231 (Agbere) with an average value of 0.59 ± 0.117. The estimated value is lower than the standard value of 1 as stipulated by UNSCEAR (2000). The estimated values for External and Internal Hazard Indices (H_{ex} and H_{in}) ranged from 0.14 ± 0.037 (0.17 ± 0.436) at Tunu community to 0.25 ± 0.081 (0.31 ± 0.104) at Agbere community with average values of 0.21 ± 0.037 (0.26 ± 0.436). The estimated values when compared with the standard values of 1 and (1) respectively were lower (UNSCEAR, 2000).

CONCLUSION

The assessment of primordial radionuclide concentrations in oil producing communities of Bayelsa West Senatorial District, Bayelsa State, Nigeria have been carried out, we herey make the following conclusions:

1. The activity concentration of ^{40}K in the soil samples were higher than the permissible limit while the activity concentration of ^{238}U and ^{232}Th were below the standard values.

2. The External and Internal hazard indices (H_{ex} and (H_{in}) were determined from the activity concentration of primordial radionuclides ^{40}K, ^{238}U and ^{232}Th and were found to be lower than the standard limit of 1 in the study area

3. The Representative Gamma Index (I_{γ}) of the soil samples in the study area is less than the world average of 1.

4. The calculated value of Annual Gonadal Equivalent Dose (AGED) in the samples on an average is less than the recommended standard limit of $300\ mSvy^{-1}$.

5. The average value of Excess Lifetime Cancer Risk in soil samples were deduced to be far lower than the recommended safe level of 0.29×10^{-3} in the study area.

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